REVIEW

Open and closed chest extrathoracic cannulation for cardiopulmonary bypass and extracorporeal life support: methods, indications, and outcomes

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Extrathoracic cannulation to establish cardiopulmonary bypass has been widely applied in recent years and includes: (a) repeat surgery, (b) minimally invasive surgery, and (c) cases with diseased vessels such as porcelain, aneurysmal, and dissecting aorta. In addition, the success and relative ease of peripheral cannulation, among other technological advances, has permitted the development of closed chest extracorporeal life support, in the form of cardiopulmonary support and extracorporeal membrane oxygenation. With this development have come applications for cardiopulmonary bypass based support outside the traditional cardiac theatre setting, including emergency circulatory support for patients in cardiogenic shock and respiratory support for patients with severely impaired gas exchange. This review summarises the approach to extrathoracic cannulation for the generalist.

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Technology supporting the implementation of cardiopulmonary bypass (CPB) has advanced beyond recognition since its introduction by Gibbon in 1953.[1] The increased versatility and safety of CPB has permitted refinement of its role within cardiac surgery. Extrathoracic cannulation to establish CPB has been widely applied in recent years and includes: (a) repeat surgery,[2] (b) minimally invasive surgery,[3] and (c) cases with diseased vessels such as porcelain,[4] aneurysm,[5] and dissecting aorta.[6] In addition, the success and relative ease of peripheral cannulation, among other technological advances, has permitted the development of closed chest extracorporeal life support (ECLS), in the form of cardiopulmonary support (CPS) and extracorporeal membrane oxygenation (ECMO).[7] With this development have come applications for CPB based support outside the traditional cardiac theatre setting, including emergency circulatory support for patients in cardiogenic shock and respiratory support for patients with severely impaired gas exchange. Increasing volumes of literature exist describing the application of extrathoracic cannulation within cardiac surgery and other specialties (emergency medicine, intensive care, and cardiology), however, no review exists summarising the indications, methods, and outcomes. This manuscript summarises the literature on open and closed chest extrathoracic cannulation as it applies to cardiac surgery and other specialties. A brief description of CPB is given as this is described well elsewhere, and then the focus is on the methodology of cannulation, indications for its various forms, and finally outcome. The topic is specialised, vast, and technically based, however we have pitched the work towards the generalist readership of this journal and those readers within the field of cardiothoracic surgery with additional interest may want to take advantage of the many web site links cited.

THE BASICS OF CARDIOPULMONARY BYPASS AND EXTRACORPOREAL LIFE SUPPORT

Principally, this manuscript examines issues around extrathoracic cannulation, however the components and process of CPB are otherwise equivalent to central cannulation. The basic circuitry for cardiopulmonary bypass has been well described and the reader is referred to http://www.pedigab.org.uk and http://www.cardiacsurgery.ctsnetbooks.org for full web based descriptions. Figure 1 shows a standard set up.[8] To perform CPB several components are needed including: venous drainage cannula, arterial return cannula, cardiotomy reservoir, heat exchanger, oxygenator, and pump. As described by Girling,[8] essentially ''cardiopulmonary bypass requires the arterialization of venous blood and its replacement into the arterial tree''. The initiation, maintenance, and separation from routine CPB, including anticoagulation and other general aspects of management are also described in http://www.cardiacsurgery.ctsnetbooks.org. ECLS set ups and management are subtly distinct from CPB for cardiac surgery and this is described below.

GENERIC ISSUES ASSOCIATED WITH EXTRATHORACIC CANNULATION

Open compared with percutaneous cannulation

Several approaches to peripheral cannulation have been described, the details of which are specific to the chosen site and whether an arterial or venous vessel is to be cannulated.

Abbreviations: CPB, cardiopulmonary bypass; CPS, cardiopulmonary support; ECLS, extracorporeal life support; ECMO, extracorporeal membrane oxygeneration; TOE, transoesophageal echocardiography; VAVR, vacuum assisted venous return; KAVR, kinetic assisted venous drainage; MAVD, modified assisted venous drainage

Detailed methodology is described below as it relates to a variety of anatomical sites, however several issues are generic and are therefore discussed first.

Generic issues in arterial cannulation

Generally, cannulation may be achieved through: (a) an open approach, (b) a semi-Seldinger method, or (c) a full Seldinger method. An open approach permits placement of a purse string and ensures correct placement of the cannula and good postoperative haemostasis. In addition, the vessels can be assessed for atherosclerosis, aneurysmal disease, and thrombosis, permitting the option to switch to other sites. An additional perceived advantage is the option to anastomose a Dacron graft permitting safer and more efficacious cannulation. Using a semi-Seldinger technique has the advantage of guidewires and dilators while permitting assessment of the vessels and the placement of purse strings through a small incision. This method has been the standard for ECLS in Leicester[9] however it is increasingly applied to extrathoracic cannulation in cardiac surgery.[10] It is particularly suitable because it has the advantages of open cannulation and the Seldinger methodology, while maintaining a minimally invasive approach. A full Seldinger method is possible however haemostasis after decannulation is achieved through external pressure and is probably only safely performed in femoral cannulations. A detailed description of each of these approaches appears below.

Generic issues in venous cannulation

An entirely percutaneous Seldinger approach is typically possible with venous cannulation whichever vessel is chosen for drainage, particularly femoral and jugular approaches. Axillary venous cannulation requires open access. After percutaneous decannulation, haemostasis may be achieved through application of external pressure. However, should access prove difficult, it is advisable to surgically expose the vessels and cannulate in a semi-Seldinger approach with or without purse string sutures for decannulation haemostasis. In femoral cannulation, it is typical to access the venous system on the contralateral side to the arterial cannula, thus avoiding cluttering of the operative field, which may be problematic with decannulation bleeding.

Flow and venous drainage

Much of the technological advances permitting extrathoracic cannulation have centred on ensuring adequate flow through gravity venous drainage, which although achievable in some patients, is not a generally reliable method in all patients. Several approaches have been developed including: (a) transoesophageal guided cannulation, (b) dual venous cannulation, (c) assisted drainage systems, and (d) tailored venous cannulas.

Several groups have advocated the use of transoesophageal echocardiography (TOE) to guide cannulation of the inferior vena cava and optimise gravity venous drainage without the need for augmentation.[11 12] Kirkeby-Garstad *et al*[11] have reported a series of 150 patients in whom they observed the open placement of their two stage Medtronic venous cannulas (36/51F in men and 34/46F in women) via the right atrium with TOE. A number of these patients underwent bicaval cannulation with cannulation of the IVC using a 28F–32F Medtronic single stage pipe. Although this study is based on central cannulation it is of interest that they show 10% of IVC cannulations entail selective cannulation of the right hepatic vein causing reduced venous drainage. They suggest that placement of the cannula deep within the IVC often accounts for poor gravity venous drainage. Of more interest in this review is the work of Toomasian and McCarthy[12] who studied venous drainage in 50 patients undergoing extrathoracic femoral cannulation. These authors found that venous flow was optimal when a multi-holed femoral venous cannula was placed at the atrio-superior vena

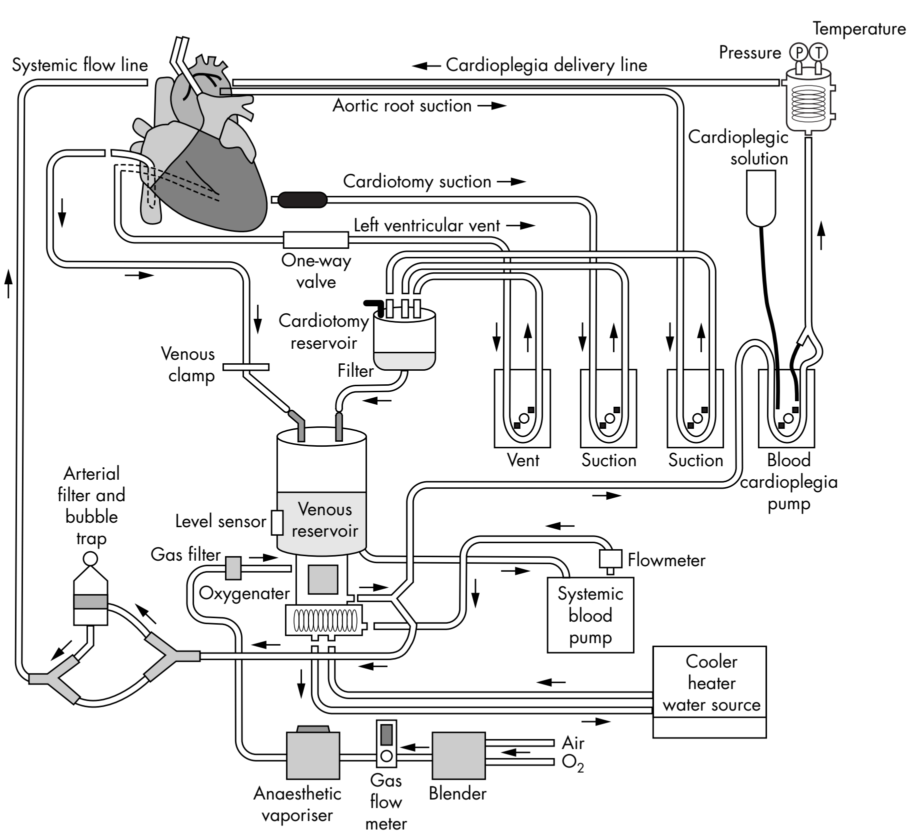

Figure 1 Cardiopulmonary bypass circuit (from *Cardiac surgery in the adult*. Cohn and Edmunds, 2nd ed).

caval junction using TOE guidance. This technique is also described by Sobieski *et al*[13] in their study of peripheral CPB for robotic assisted mitral valve repair. They optimised placement of their augmented RIJ venous cannula at the atrio-superior vena caval junction using TOE. A number of other studies advocate this technique.[14]

As described by Sobieski *et al*[13] there are three approaches to augmenting venous drainage over simple gravity set ups. These include: (a) vacuum assisted venous return (VAVR), (b) kinetic assisted venous drainage (KAVD), and (c) rollar pump assisted venous drainage or so called modified assisted venous drainage (MAVD). Sobieski *et al*[13] report successfully using modified assisted venous drainage system during robotic repair of the mitral valve. Extrathoracic cannulation was established using a Duraflo coated closed circuit with femoral arterial and venous cannulation permitting gravity drainage of the lower body (25-27F Bio-Medicus femoral venous cannula). Additional venous drainage of the upper body was achieved using a 17 F wire bound cannula inserted into the right internal jugular vein (200–400 ml/min), regulated using a separate roller head. Augmentation of flow via the IJV was titrated to ensure decompression of the heart and a bloodless field. These authors prefer this approach as they believe it avoids the additional costs and risks of kinetic and vacuum assisted venous drainage. However, caution has been advocated by Toomasian and McCarthy[12] as unregulated rollar pump assisted venous drainage can generate extreme negative pressures resulting in cavitations, haemolysis, and air to be entrained. Dual venous cannulation has been advocated for percutaneous CPB by Aybek *et al*[15] in their study using Port-Access technology for mitral valve surgery, however Toomasiian and McCarthy[12] suggested a second unaugmented venous cannula is not an effective solution. These authors suggest kinetic assisted venous drainage by application of controlled suction permits adequate flow through a single cannula providing a multi-holed cannula positioned correctly is used. These authors report regulating the kinectic assisted venous drainage syphon to −50 to −80 mm Hg by measuring the kinetic pump inlet pressure, thus preventing excessive pressure, line chatter and collapse of the RA. There is an inherent risk of aspirating air into the venous line causing airlock, particularly if the line is not secure, the RA is opened, or there is a PFO when the left heart is opened.[12] Sobieski *et al*[13] have pointed out that these systems are susceptible to airlocks. In addition, vacuum assisted venous drainage using a centrifugal pump (−43 ± −14 mm Hg) has been shown to be effective by Shin *et al*[16] in their study of 40 patients undergoing minimally invasive cardiac surgery. These authors, and others,[17] prefer this approach as they state it permits small cannulas and shorter tubing to be used with lower priming volume. McCusker *et al*[14] have described high flow femoro-femoral bypass using small cannulas and a centrifugal pump on the venous side (VAVR) in a Y based circuit allowing the augmented venous return to be excluded from the circuit as appropriate. These authors describe using thin walled flexible DLP cannulas permitting percutaneous placement. However, several authors have expressed concerns regarding the potential for the high vacuum pressures to cause microbubbles to pass into the arterial line.[17 18] The nature of the venous cannula is an important variable in achieving adequate gravity venous drainage. Jegger *et al*[19] studied the flow dynamics of various commercially available venous cannulas used with centrifugal pumps. Using an experimental system they concluded that the total hole area, in addition to internal diameter and length, was a critical factor in determining drainage through a venous cannula. Interestingly, Laub *et al*,[20] in animal models, reported the successful use of a percutaneous self expanding venous basket that prevents collapse obstructing flow. In addition, Jones *et al*[21] report the use of an ultra-thin non-kinkable catheters (25F, 27F, and 29 F) that permitted adequate drainage in 35 patients without the need for augmented drainage. Another approach has been to use an in vitro experimental system to study factors affecting venous drainage in simulated femoro-femoral CPB.[22] The authors showed venous drainage flow was directly related to siphon gradient and right atrial pressure and inversely related to inferior vena caval flow.

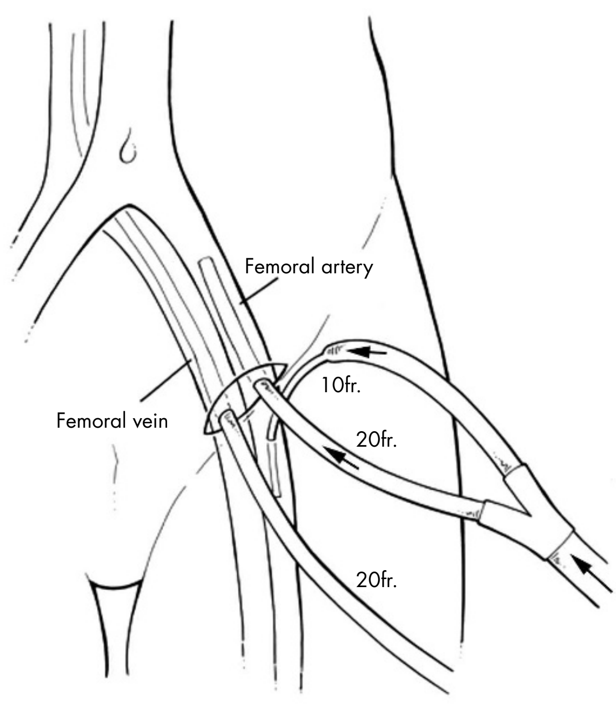

Figure 2 Femoral cannulation (from *Cardiac surgery in the adult*. Cohn and Edmunds, 2nd ed).

Several studies have examined the effect of assisted venous drainage on haematinics and Banbury *et al*[17] have concluded that vacuum assisted venous drainage results in higher packed cell volume values during CPB and decreased red cell and total blood product usage. Shin *et al*[16] showed that this approach does not appreciably increase haemolysis compared with traditional CPB.

One other approach described for the problem of inadequate gravity venous drainage is ''permissive partial cardiopulmonary bypass''. This approach entails initial peripheral cannulation and maximum obtainable CPB, permitting collapse of the RV for sternotomy. Ventilation is maintained until full bypass is achieved. After exposure of the RA, central cannulation permits full CPB.[2 14]

In summary, a variety of options are now available to achieve adequate venous drainage including: (a) TOE, (b) dual venous cannulation, (c) assisted drainage, and (d) tailored cannulas. An acceptable approach includes TOE guided placement of an appropriate venous cannula, while optimising preload and gravity, to permit adequate venous drainage and full flow CPB. If this fails to achieve an adequate cardiac index, then venous drainage may be augmented either by MAVD, KIVD, or VAVD.

ISSUES ASSOCIATED WITH SPECIFIC EXTRATHORACIC CANNULATION SITES

In this section we discuss each cannulation site and the data presently available describing outcome. The anatomy and methodology relevant to cannulation is described.

Femoral cannulation

Femoral artery cannulation has become the commonly accepted norm for peripheral cannulation as indicated by a range of pathologies (aneurysmal aorta or acute aortic dissection) and scenarios (repeat or minimally invasive surgery).[2 4 14 23] Ease of access to comparatively large calibre vessels has popularised this approach, and all three cannulation methodologies have been successfully applied (fig 2).

Methodology

Seldinger cannulation

As described, a number of publications describe percutaneous Seldinger cannulation of the femoral vessels for CPB based cardiac surgery[24] however more commonly this technique is used in closed chest cardiopulmonary support.[25–33] Several authors describe percutaneous cannulation with the aid of angiographic imaging, particularly those studies using closed chest percutaneous cardiopulmonary support in the catheter laboratory.[25] These authors have described their approach in detail, however the Seldinger technique is now ubiquitous in medicine.[34] After heparinisation, and using strict aseptic technique, the common femoral artery is accessed below the inguinal ligament with a wide bore needle (18 gauge). A flexible J tipped guide wire is introduced through the arterial sheath and advanced into the descending aorta. After a skin incision, graduated dilators are passed over the wire in a serial manner until sufficient access is gained to permit the arterial cannula (18–20F,[25] 18F,[28] 18F,[30] 15–19F,[31] 19F,[32]) to be advanced. Once the arterial cannula is in situ, the guidewire and dilator are removed. A similar technique is used to cannulate the contralateral femoral vein, the size dependent on the system of venous drainage (21–24F,[24] 18F,[25] 18F,[28] 18F,[30] 17F–23F,[27] 21F,[32]). As described earlier, after decannulation external pressure is applied to the groin to secure haemostasis. A Femstop may be applied to aid haemostasis.

Semi-Seldinger cannulation

This is the preferred method of the senior author (AS) and has been described previously by him and his coauthors in a number of scenarios.[9 10 35] A modified DLP 21F arterial line is our preferred cannula for femoral access. A small transverse incision is made directly over the femoral artery and deepened to expose a short length of the common femoral artery. The arterial puncture needle is introduced via a separate stab incision 2 cm caudal to the transverse incision and is inserted into the artery under direct vision. This method of insertion allows the arterial cannula to lie nearly parallel to the artery and prevents over-angulation and kinking at the entry site. Through the lumen a guidewire is passed cephalid. Serial dilatation is then performed of the arterial puncture using short dilators and the arterial cannula passed into the CFA over the long dilators ensuring that all the side holes are within the artery. The cannula may then be connected to the bypass circuit for arterial return. A 5-0 Prolene purse string may be used to secure haemostasis at the end of the procedure. Our approach to venous drainage has been to cannulate the contralateral femoral vein or right internal jugular vein by entirely Seldinger methods using a modified DLP system. The femoral vein is initially accessed by venepuncture using an Angiocath 16 GA cannula. A guidewire is passed through the central lumen of the venous cannula ensuring it traverses freely within the lumen. Sufficient length is passed so that the tip of the guidewire lies well within the vena cava. After making a small stab incision at the entry point, dilators are passed over the guidewire and graduated dilatations of the femoral vein are carried out. The venous cannula is then assembled over the two long dilators and the whole assembly is passed over the guidewire introducing each dilator in turn by sliding one over the other into the femoral vein. When successfully in place the guidewire and long dilators are removed and the venous cannula connected in the circuit.

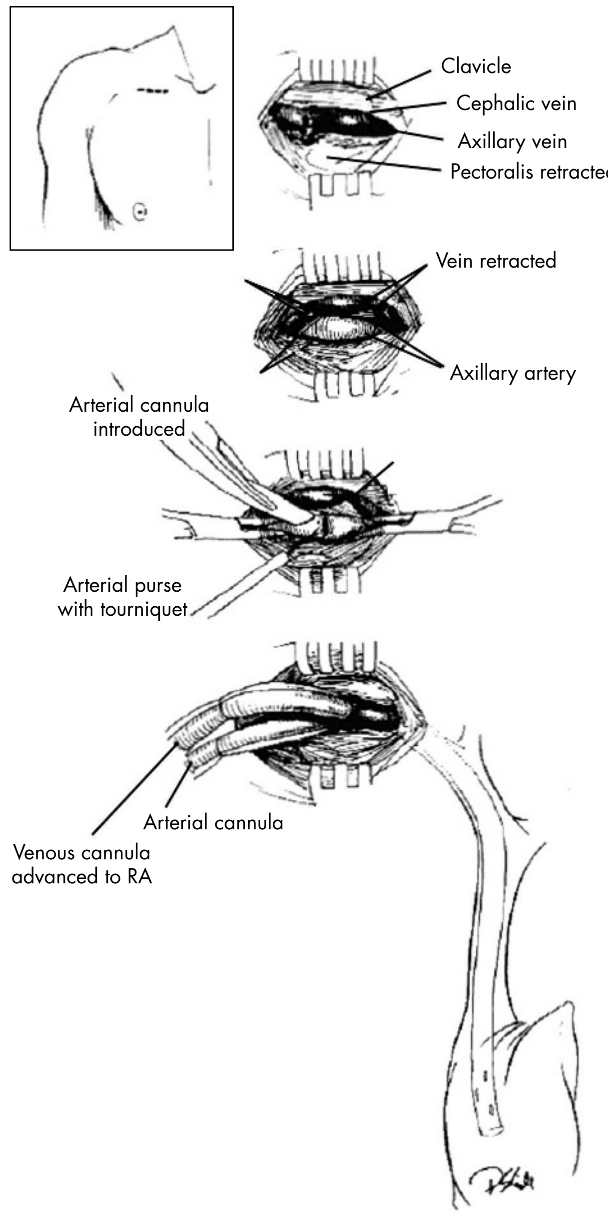

Figure 3 Axillary cannulation (From Bichell *et al. Ann Thorac Surg* 1997;**64**:702–5).

Open cannulation

Femoral cutdown is the traditional surgical approach to cannulation. A transverse skin crease incision is made over the femoral vessels below the inguinal ligament. The common femoral artery and femoral vein are dissected free and vascular slings used to gain control. 5-0 Prolene is used to create purse strings in both vessels. After heparinisation and arteriotomy, the vessels are cannulated directly. Decannulation is a simple affair with direct access to the vessels to secure haemostasis.

Vander Salm *et al*[36] in the "*How to do it*" series in ATS has advocated the use of a 10 mm PTFE graft through which to cannulate. This lowers the risk of distal leg ischaemia and dissection as well as simplifying decannulation. It does

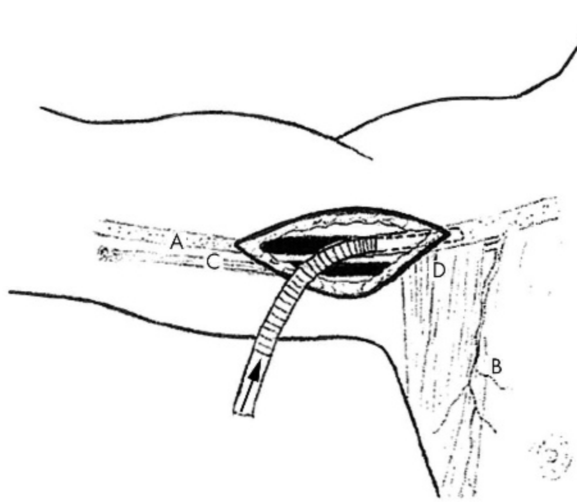

Figure 4 Brachial cannulation (From Galajda *et al. J Thorac Cardiovasc Surg* 2003;**125**:407–9).

however prolong the duration of cannulation. Another approach to preserving distal limb viability has been to arrange a Y connector permitting both proximal and distal perfusion relative to the arteriotomy. Should a patient be of small stature with small femoral vessels the external iliac artery may be dissected for cannulation.[24]

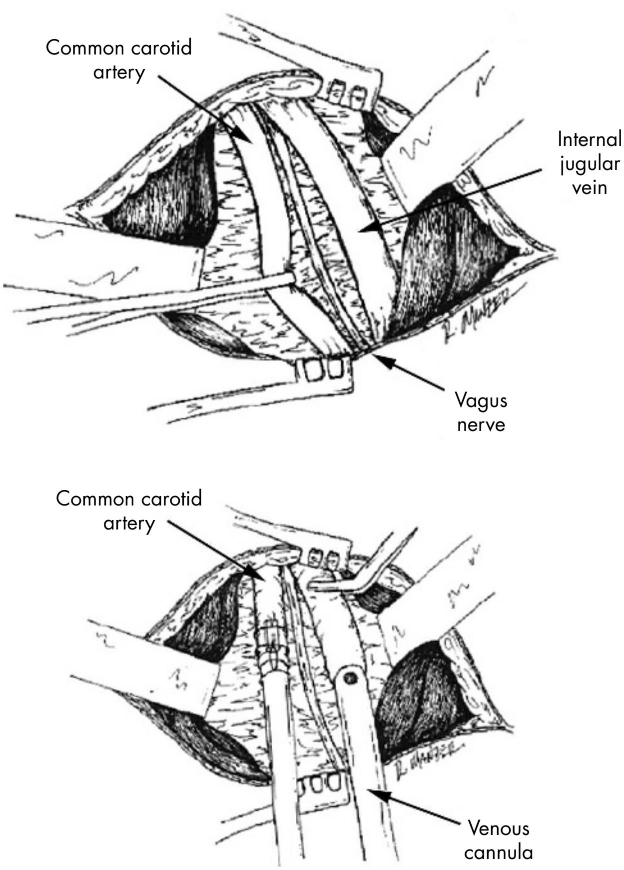

Figure 5 Cervical cannulation (From Richenbacher WE. *Mechanical circulatory support.* Vademecum, 1999).

Indications and outcomes

Femoral based CPB has been applied successfully to a number of scenarios in cardiovascular surgery. Repeat cardiac surgery carries significant risk of laceration to the right ventricle, tearing of patent grafts, including IMA and embolisation from patent grafts. Merin *et al*[2] have advocated the use of femoro-femoral bypass before repeat sternotomy stating the following reasons: (a) early CPB offers better myocardial protection especially in the unstable patient; (b) decompression of the heart during sternotomy reduces the risk of trauma to the myocardium and grafts, particularly when the right heart is dilated, (c) less manipulation of the aorta already crowded by previous grafts, and (d) less myocardial ischaemia in the event of graft injury. The approach to cannulation for repeat surgery is often based on a surgeon's assessment of the risk of injury on repeat sternotomy. Surgeons may choose simply to prepare and expose the groin area for cannulation should it be required urgently, while others may formally dissect the femoral vessels before sternotomy but stop short of cannulation. The approach should be tailored and based on an assessment of risk.

Minimally invasive techniques using a small right lateral minithoracotomy and femoro-femoral bypass have gained widespread application recently in primary and repeat mitral surgery.[12 13 16 23] The extrathoracic cannulation site of choice has been femoral particularly with the HeartPort system. Peripheral cannulation aids in reducing the clutter within a small operative field and adds to the minimally invasive ethos of these approaches.

Porcelain aorta precludes central cannulation and cross clamping, requiring an alternative approach unless total arterial revascularisation-OPCAB surgery is an option. Accepted approaches include[4]: femoral cannulation with hypothermic fibrillatory arrest and femoral cannulation with hypothermic circulatory arrest, with or without interposition tube graft repair. As will be discussed later, these patients often have severe peripheral vascular disease and alternate extrathoracic cannulation sites (brachial or axillary) are often preferred to avoid ischaemic complications and permit anterograde flow. Another approach is the use of a percutaneous HeartPort endovascular balloon catheter to "cross clamp" and give cardioplegia.

Emergency percutaneous closed chest cardiopulmonary support has been applied to a number of clinical scenarios principally in the USA since 1986. Support is typically initiated through percutaneous femoral cannulation.[25–33] Applications have included: cardiac arrest in the catheter laboratory, high risk coronary angioplasty/valvuloplasty, cardiogenic shock, pulmonary embolism, intractable ventricular arrhythmias, hypothermia, near drowning, drug overdose and the reader is referred to reviews of the topic by Shawl and Baxley,[25] and Overlie,[26] Ludwig von Segesser[7] in particular gives a good review of ECLS comparing CPS and ECMO, and this will be discussed further below with respect to different approaches to cannulation in these two modalities.

However, a number of concerns have been expressed regarding femoral cannulation in patients with severe peripheral vascular disease or aneurysmal vessels.[6 37–41] In addition, these authors have raised the issue of malperfusion of organs because of the retrograde nature of flow from this site. Lastly, there are a number of site specific complications associated with femoral cannulation. The most significant complication is of distal limb ischaemia and reperfusion injury, however other morbidities include: pseudoaneurysm, neurological injury, compartment syndrome, retrograde dissection, dislodgement embolisation of luminal debris, and wound complications such as lymphocele, infection, and haematoma.[2] In a series of 389 patients undergoing femoral cannulation, Teirstein *et al*[42] report an incidence of femoral artery occlusion of 2.5%. These authors report an incidence of femoral pseudoaneurysm, 0.8%, deep vein thrombosis, 0.8% and wound haematoma, 5.4%. Several authors have advocated the use of end to side femoral artery grafts that permit distal limb perfusion as well as reducing the risk of vessel dissection. In addition, this approach permits larger bore cannula to be used and aid the decannulation process.[43] Other approaches include bidirectional arterial cannulas and augmented distal run off through SFA cannulation.[44 45] These issues have led to the popularisation of the axillary and brachial vessels as alternative cannulation sites.[6 37–41]

Axillary cannulation

As suggested, although the femoral vessels remain the commonest site for extrathoracic cannulation, axillary vessel cannulation is becoming increasingly common.[37–41]

Methodology (fig 3)

The technique is well described by Schachner *et al*[39] and Watanabe *et al*[41] both in the ''*How to do it*'' series of the EJCTS. Techniques do vary however and other descriptions have been published.[6 37–40] An incision is made in the sub-clavicular region at the mid to lateral point. The pectoralis major muscle is incised and the fibres split, securing haemostasis and preserving the lateral pectral nerve. The cephalic vein and thoraco-acromial vessels may need division. Pectoralis minor may be retracted laterally. Identification and retraction of the subclavian vein permits visualisation of the artery. Care is taken to avoid the brachial plexus lying posteriorly. After heparinisation, proximal and distal control of the vessel is attained and the vessel clamped. A purse string may be placed.[37 38] A transverse arteriotomy is made and the vessel cannulated directly with a: 20–22F Sarns cannula or 19F percutaneous arterial femoral cannula (Bio-Medicus),[41] 20–22F DLP (Medtonic),[39] 20–22F straight arterial cannula,[6] 20–22F Sarns flexible arterial cannula,[38] or 20–22F right angled arterial cannula.[37] If the plan is to go on CPB before opening the chest, then the femoral vein may be cannulated and the tip guided to the RA with TOE.[37 40] Otherwise the RA may be cannulated directly once the chest is opened. Bichell *et al*[38] describe cannulation of the axillary vein through a purse string using a 25–27F Biomedicus venous femoral cannula. Placement of the cannula into the RA was confirmed on TOE. All the seven patients in their series achieved flow rates of more than 3 l/min without difficulty.

Depending on the size of the vessel, a 8–10 mm Dacron or Gortex tube graft may be anastomosed to the vessel and cannulated.[39–41] After decannulation the axillary artery may be repaired with 5-0 Prolene or the graft amputated and oversewn.

No less invasive approach has been described.

Indications and outcomes

Watanabe *et al*[41] report that their primary alternative access for a diseased ascending aorta is the femoral artery, however the axillary (or transapical) site is chosen for: (1) coexisting abdominal or iliac aneurysms; (2) coexisting chronic peripheral arterial occlusive disease; (3) dissection of femoral artery because of extensive dissection; and (4) considerably narrow true lumen with crescent shape compressed by the false lumen in aortic dissection. Additional perceived advantages of axillary artery cannulation include anterograde aortic flow with decreased risk of atheremboli and avoidance of organ malperfusion. In addition, the groin with the inherent risk of infection may be avoided. Limb ischaemia is less likely because unlike the lower limb blood supply, there is a rich collateral supply in the shoulder girdle. The site is particularly suited to aortic surgery in that the venous cannula may be manipulated into the SVC permitting retrograde cerebral perfusion,[37 38] or selective anterograde cerebral perfusion via the right axillary artery.[40] Bichell *et al*[38] suggest in a series of seven patients, that axilloaxillary CPB is an increasingly attractive option given the patient population we increasingly operate on, namely those with severe peripheral vascular disease. Sinclair *et al*[40] have reported a series of 75 patients who had axillary artery cannulation for reoperations, dissections and diseased aortas. The right axillary artery was cannulated in 72 patients and the left in three patients. In 59 patients the arterial cannula was inserted through a prosthetic graft anastomosed to the axillary artery and in 16 patients the artery was cannulated directly. Neri *et al*[6] report a series of 152 operations for aortic dissection, 22 of whom had axillary artery cannulation (left, 20; right, 2). No patients suffered axillary artery thrombosis or brachial injury. Schachner *et al*[39] report 20 patients who underwent aortic surgery with axillary artery cannulation via an end to side Gore-tex graft. In two patients, conversion to femoral artery was necessary and they had no complications. Sabik *et al*[37] report another 35 patients who underwent axillary artery cannulation because of the presence of atherosclerosis and aneurysmal disease. One patient required axillary artery thrombectomy and another sustained ipsilateral brachial plexus paraesthesia. Miyatake *et al*[46] have reported a case in which axillary artery cannulation led to dissection and they recommend TOE to monitor this potential complication.

Brachial cannulation

Brachial vessel cannulation has been advocated for similar clinical scenarios as axillary cannulation, however it has been touted as superior in terms of safety and efficacy.[47 48]

Methodology (fig 4)

Detailed descriptions of the surgical approach to cannulation at this site have been given by Tasdemir *et al*[47] and Galajda *et al*[48] and is reproduced here. The patient is placed supine with the upper limb abducted (70–90°) and externally rotated. A longitudinal incision (6–8 cm) is made between the belly of biceps and triceps extending into the axilla. The medial border of biceps is identified and retracted anteriorly, exposing the neurovascular bundle under an aponeurotic sheath. This fascia in incised and the median nerve retracted laterally and the ulna nerve retracted medially. The artery is exposed and slings placed proximally and distally. After heparinisation the vessels is clamped and a transverse incision performed. The vessel is cannulated with 20F Fem-Flex femoral artery catheter (Baxter),[48] or a 16–18F non-wire reinforced venous return catheter (CML).[47] After decannulation the vessel may be repaired with 5-0 Prolene. In these descriptions venous return is via a two stage cannula in the right atrium. There seems to be no reports describing brachial vein cannulation. No less invasive approach has been described.

Indications and outcomes

The brachial vessels seem to be an attractive option for extrathoracic cannulation, with similar and additional advantages to axillary cannulation. In particular, the cannulation site is a good distance from the aortic arch and therefore any post-cannulation iatrogenic dissection has less chance of dissecting into the aortic media. In addition, the distal nature of the cannulation site allows for perfusion through the periscapular collateral circulation via the subscapular artery. Lastly, exposure of the vessels at this site has been reported as comparatively easy. Tasdemir *et al*[47] do report using dual arterial return (femoral) with their initial patients, however subsequently they found sufficient flow rates could be achieved with brachial cannulation alone. The

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right brachial artery is preferred as it permits repair of the distal aortic arch while retaining the ability to perform selective anterograde cerebral protection via the brachiocephalic artery. These authors have reported a series of 104 ''arch repairs'' (Stanford type A aortic dissection, 64; aneurysmal dilatation of ascending aorta and arch, 38; isolated arch aneurysm, 2). All patients underwent anterograde cerebral perfusion (8–10 ml/kg/min), via the right brachial artery after clamping the brachiocephalic artery, under moderate hypothermia (26℃). One patient died from cerebral complications and another developed a transient right hemiparesis. They conclude that right brachial artery cannulation permits full CPB, as well as selective anterograde cerebral perfusion, negating the need for DHCA and permitting shorter CPB times.

Cervical cannulation

Cervical cannulation is used widely for extracorporeal life support as ECMO in neonates, and more recently in other patient populations, but is not common in cardiovascular surgery as access for CPB.[12] The exception to this is an important role for percutaneous cannulation of the RIJ vein as dual access augmented venous drainage.

Methodology (fig 5)

ECLS specific cannulation

We (Andrew Sosnowski and coauthors) have previously published our preferred extrathoracic cannulation techniques for ECLS and CPB[9 10 35] and the description is reproduced here.

Veno-venous cannulation

For patients less than 6 kg in respiratory failure, a double lumen cannula permitting double lumen venovenous access for ECLS is the preferred approach. The method used at our institution (Glenfield Hospital) is a semi-Seldinger technique.[9] Size 12F and 15F cannulas are available from Jostra and a 14F cannula is available from Kendal. The patient is positioned supine with the head turned to the left. General anaesthetic with neuromuscular block lowers the risk of air embolism. The RIJ vein is exposed via a transverse incision over the lower third of the sternocleidomastoid. The vein is dissected and a sling passed around the proximal aspect. A small stab incision is made cephalid to the main incision, and after heparinisation (50 IU/kg), the introducer needle is passed through this stab into the vein. Exposure of the vein allows for sizing of the cannula and monitoring for tears/avulsion during dilatation. The guidewire is passed through the needle, followed by the dilators, and then the cannula. The proximal sling may be used to provide counter traction. The cannula tip is positioned into the right atrium. The wound is packed with Surgicel and Tisseel glue and then closed in layers. Before decannulation a purse string is placed around the stab incision, and tied on withdrawl of the

Web sites

- Heart Surgery Forum (http://www.hsforum.com). A cardiothoracic multimedia journal and the official publication of the International Society for Minimally Invasive Cardiothoracic Surgery. Contains discussion and video clips on relevant topics.
- CTSnet (http://www.CTSnet.org). A cardiothoracic discussion forum on relevant topics.
- Interactive Cardiovascular and Thoracic Surgery (http://www.sciencedirect.com/science/journal/15699292). An interactive journal containing discussion on relevant topics.
- Recommendations for standards of monitoring and alarms during cardiopulmonary bypass. (http://www.scts.org/file/bypassrecommendations.pdf). Standards required by the Society of Cardiothoracic Surgeons.
- Extracorporeal life support organisation (http://www.elso.med.umich.edu). Mine of information on technical aspects of extracorporeal life support.
- Cardiopulmonary bypass (http://www.pediheart.org). Descriptions of cardiopulmonary bypass and its application.

Patient Information

- Royal Hospital for Sick Children, Glasgow. (http://www.gla.ac.uk/departments/surgicalpaediatrics/ecmoinfo.htm).
- Great Ormond Street Hospital for Children NHS Trust. (http://www.ich.ud.ac.uk/factsheet).

Relevant trials, registries, and studies

- UK neonatal ECMO trial. (http://www.ich.ud.ac.uk/ecmo/ecmo-trial).
- Conventional ventilation or ECMO for severe adult respiratory failure (CESAR trial). (http://www.cesar-trial.org/ecmo.pdf).
- Extracorporeal life support organisation (http://www.elso.med.umich.edu). Worldwide registry of patient episodes.
- Extracorporeal membrane oxygenation for severe respiratory failure in newborn infants. Elbourne D, Field D, Mugford M. *Cochrane Library*. Issue 4. Chichester: Wiley, 2004. (http://www.nelh.nhs.uk/cochrane.asp).
- BestBETs series. Cardiopulmonary bypass and the survival of patients in cardiac arrest. Joel Dunning, 2004. (http://www.bestbets.org).
- Best BETSs series. Bypass is better than external rewarming after hypothermic cardiac arrest. Claudia Webster-Smith, 2000. (http://www.bestbets.org).

Guidelines

- National Institute of Health and Clinical Evidence (NICE). Interventional procedures consultation document—extracorporeal membrane oxygentation (ECMO) in postneonatal children. (http://www.nice.org.uk).
- ELSO Guidelines for Neonatal ECMO Consultation. (http://www.elso.med.umich.edu).
- ELSO Guidelines for Neonatal ECMO Centres. (http://www.elso.med.umich.edu).
- ELSO Guidelines for Training and Continuing Education of Neonatal ECMO Specialists. (http://www.elso.med.umich.edu).
- ELSO Recommendations for Follow-up ECMO Patients. (http://www.elso.med.umich.edu).

cannula. This approach does not require ligation of the vein and facilitates the process of decannulation. Not ligating the RIJ vein allows drainage of de-oxygenated blood down the ipsilateral vessel and into the cannula. This reduces recirculation and may also have an impact on intracranial venous pressure and the incidence of intracranial haemorrhage.

In two cannula VV the total flow in the circuit is determined by the size of the venous cannula and the height of the venous syphon. The best venous drainage can be obtained via the RIJ vein that permits the insertion of large, short, cannulas. The return cannula can be inserted in either femoral vein. When initiating VV ECLS, low flow should be used until mixing of the patient's blood and prime has occurred.

Veno-arterial cannulation

As previously described by ourselves[35] VA support is indicated for haemodynamic instability permitting cardiac support, or when VV cannulation is not technically possible. The right carotid artrery and right internal jugular vein are the vessels typically used. The vessels are exposed as described previously for the double lumen cannula. The internal jugular and carotid artery are dissected and slung, following which heparin is given. After arteriotomy the cannula is inserted and secured with the tip of the cannula placed at the orifice of the innominate artery. The venous cannula is inserted a similar manner.

Indications and outcome

Ludwig K von Segesser[7] has published a review and the reader is referred to this for a full analysis. As suggested, there are two concepts in ECLS, that of CPS and ECMO. CPS was discussed earlier with respect to femoral cannulation as this is the primary access for this treatment modality. A mobile cart is used, which is small relative to CPB set ups. Typically, the stack has a single centrifugal pump, battery backup, oxygen supply, and heater; noticeably lacking a reservoir. Percutaneous arterial cannulas measure 17–21F while venous cannulae measure 20–24F. Venous pipes feed directly into the centrifugal pump that drives volume through the oxygenator and heat exchanger before returning blood to the arterial line. Flow rates of 3–4 litres per minute are achievable. There has been a vast array of applications for this technology and the reader is referred elsewhere for a critical appraisal, sufficient to say the list includes: cardiogenic shock, angioplasty, donor preservation, bridging to ventricular assist devices, trauma, and apheresis.[25–33] As stated by von Segesser,[7] CPS is not generally suitable for long term use because of the comparatively small bore cannulas and simple technology, and its application is for brief support or as a bridge to definitive intervention. ECMO has different indications and is designed for longer term support using more sophisticated pumps, heaters, and oxygenators. Specialised cannulas permit higher flows with reduced gradients, and as indicated access is gained through cervical cannulation. As shown previously, ECMO may be run in a VA or VV mode depending on cannulation. The details of ECLS as it applies to the running of perfusion are well described in http://cardiacsurgery.ctsnetbooks.org.

The ELSO ECMO registry based at the University of Michigan suggests that use of ECMO for cardiac support, primarily in paediatric surgical patients, has a survival around 40%. This compares with a survival of around 80% when ECMO is used for respiratory support in neonates. Efficacy of ECMO for respiratory failure in neonates is evidenced based after publication of the ''UK collaborative randomised trial of neonatal ECMO'' by the UK Collaborative ECMO Trial group (1996). The indications for this technology is fluid and in development with respect to paediatric and adult populations.

Subclavian artery

Whitlark and Sutter[49] have reported the use of the left intrathoracic subclavian artery for cannulation when performing surgery through the left chest. Their description includes use of a right angled cannula introduced through a 5-0 Prolene purse string.

CONCLUSIONS

Extrathoracic cannulation to establish CPB has been widely applied in recent years and includes: (a) repeat surgery,[2] (b) minimally invasive surgery,[3] and (c) cases with diseased vessels such as porcelain aorta,[4] aneurysmal aorta,[5] and dissecting aorta.[6] The approach has resulted in technically improved procedures with better outcomes, including the development of robotic assisted surgery. Of those using peripheral cannulation for complex cardiovascular surgery, many have moved away from femoral cannulation towards axillary and brachial approaches. In part this has been driven by a need to reduce the complications of femoral cannulation as detailed above, but more importantly, the axillary and brachial cannulation approaches are much more conducive to advances in brain protection and the gold standard of anterograde cerebral perfusion.

Further recent advances in technology around extrathoracic cannulation have permitted the development of the Heartport endoclamp in minimal access mitral valve surgery.[3 51] The device is a balloon tipped catheter that is passed into the ascending aorta under TOE guidance and once inflated becomes occlusive effectively cross clamping the aorta. Multiple lumens permit delivery of cardioplegia into the root and subsequent venting. The device is delivered through a port in the arterial catheter and has advanced the abilitity of minimally invasive enthusiasts to perform increasingly complex surgery.

In addition, the success and relative ease of peripheral cannulation, among other technological advances, has permitted the development of closed chest extracorporeal life support, in the form of CPS and extracorporeal membrane oxygenation.[7] With this development has come applications for CPB based support outside the traditional cardiac theatre setting, including emergency circulatory support for patients in cardiogenic shock and respiratory support for patients with severely impaired gas exchange. Additional developments in percutaneous venting, selective anterograde coronary perfusion, and synchronised coronary sinus retroperfusion will permit improved outcomes in closed chest ECLS.

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